B.1. Overview

Motorola is in the development phase of an E-OTD system. For the trial system they installed special data gathering equipment at a number of cell sites covering the trial area and utilized laptops connected to the iDEN phones that performed the initial position determination. Post processing of the data at Motorola facilities led to the location data provided in this report.

The results presented here are based on the trial conducted from June 2nd to June 7th, 2000 in the Washington, D.C. trial area as defined in the Nextel's Location System Field Evaluation Test Plan dated March 13th, 2000.

The Motorola system tested can best be described as an R & D data gathering system, as there was no real time reporting of any location information. A set of 12 calibration units were deployed at the base sites around the test area and laptops were connected to the modified i1000 test phones. Those phones were not configured for voice communication but rather "listened" to transmissions from the surrounding cell sites. Due to the developmental state of the system, no mobile tests were deemed appropriate. Also care was taken to eliminate potential interference from other Nextel users in the area. After the testing, the data was gathered from the laptops and calibration units by Motorola and was analyzed to provide the location fixes.

During the test period a substantial list of operational problems and equipment errors and malfunctions were experienced. These problems adversely affected the results and are detailed in a subsequent section of this appendix. Motorola therefore requested the elimination of several test runs.
The yield for all the 3819 calls made was 48% whereas the yield for the selected samples of 1231 (i.e., excluding the data associated with the problems encountered) was 72.6%. The positioning performance was generally better in suburban areas and worst for indoor settings. The exclusion of the problematic data samples did improve the accuracy at most points, yet the FCC mandate was not satisfied at any of the locations tested. Overall, the 67 percentile for positioning error improved from 545 m to 462 m—well outside the FCC requirements. The 95 percentile was too high to meaningfully report.

The results detailed below show the need for substantial further development of the system with improvement to its location algorithm.

B.2. Configuration of Test System

The Motorola test system consisted of a set of calibration units that were deployed to base sites and laptops connected to modified i1000 test phones. The calibration units known as HAMRs were used to record the time-of-launch (TOL) error which is the difference between the GPS time and the time stamp provided by the base radios (BRs).

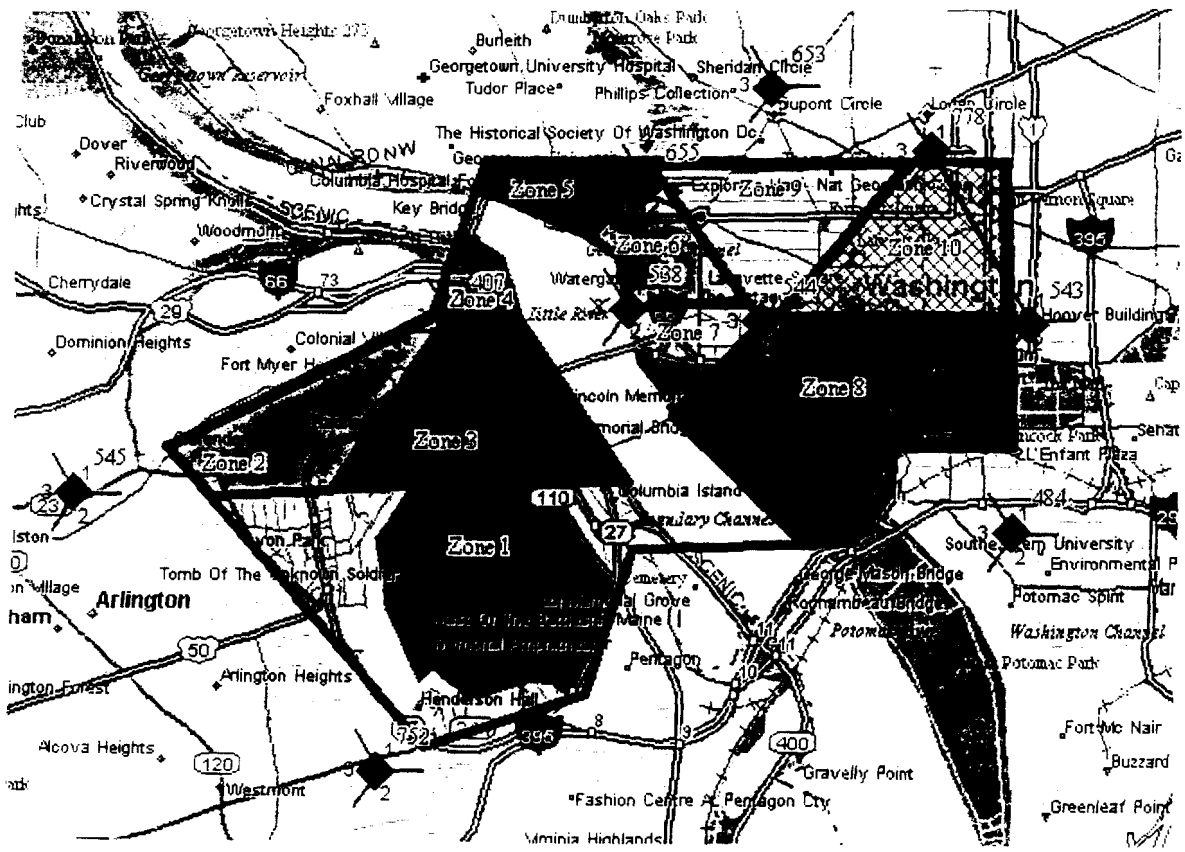
The errors were logged on PCs whose system clocks were synchronized to roughly +/- one minute. During field testing, time difference of arrival (TDOA) measurements were made by a specially modified i1000 that listened to nearby base sites. Raw TDOA data generated by the subscriber was logged by PCs whose system clocks were synchronized (again with roughly +/- one minute accuracy) to the system clocks in the calibration PCs. TDOA measurements were made for a user specified interval (typically 1-3 seconds), and were then output to the PC over a serial connection.

The data collected in the field was post processed along with the TOL errors that were collected from each base site during the testing. That data was synchronized with the raw TDOA data using the time stamps on the log files (for rough alignment) in conjunction with the slot numbers (for final alignment) and applied to the raw TDOAs. The location calculations were made using the corrected data.

B.2.1 Area Boundaries and Motorola Deployment

The trial area utilized for Motorola was identical to the area outlined in the test plan. A total of 12 calibration units were deployed on Nextel sites in the area. As depicted in Figure B.2-1, these calibration sites created twelve coverage zones. Each calibration location monitored 4 to5 other sites and gathered data for location calculation.

Figure B.2-1 Motorola Coverage Zones



B.3. Mode of Operation

The mode of operation for Motorola can be best described as a Data Gathering system. No voice communication was involved in these tests.

B.3.1 Deviation from Test Plan

Several aspects of Motorola's system did not match the test plan. The deviations are as follows:

- The handset did not place a call, but rather "listens" to traffic and idle slots from multiple sites. In fact, the modified i1000's were not configured to place or receive calls at all.
- Due to the non-real time nature of the test setup, time stamping of the data was deemed to be meaningless, thus eliminating the need for the mobile test setup.
- All moving tests were deemed inappropriate for the trial system.
- The determination of the exact moment a measurement was taken and the accurate position determination is done in post-processing. Data was not provided to TechnoCom on a daily basis.
- Due to the experimental nature of the system, care was taken to eliminate any interference from other Nextel phones in the area.
- Based on information received from Motorola after the trials, several test runs were eliminated due to system failures. The failures as reported by Motorola are as follows:
  - HAMR corrections from the National Archives site were corrupt for the entire first day of testing.
  - Motorola was unable to make a change in the color code of the NE sector of South Arlington until reviewing the data on the third day of testing. All data taken on the first two days at locations utilizing the South Arlington site missed that site. The correct color code was entered into the scan lists for testing on the remaining three days.
  - The Kennedy Center HAMR was not operational during the first half day of testing on the first day of tests. All data taken at locations that would have used the Kennedy Center site was missing that site during that time.
  - Certain sites performed a timing correction procedure while data was being collected. This led to unusable HAMR timing error corrections during those periods. It should be noted that this procedure would not have occurred if the timing loop software upgrades for all sites were implemented.

- A software setup error resulted in taking some data on the third and forth days of testing that should have used the Kennedy Center without including it in the scan lists.
- Test location 18 was listed as being in zone 9 when it was actually in zone 8.
- Test locations 19, 20, and 31 were listed as being in zone 8 when they were actually on zone 11. Zone 11 was added to the diagram late and was not as visible in the test area map that was utilized. This issue was resolved after two days of tests.
- In addition to hurting the geometry (HDOP) of the location solution, missing sites also reduced the amount of data collected in some cases. This reduced the amount of averaging that could have been performed.
- Low signal-to-interference levels received from HAMR-equipped base sites resulted from covering the entire test area with just 10 HAMRs.

The results presented here provide the statistics based on all the data and separately the statistics of the selected data files.

B.4. Trial Results

B.4.1 Stationary Tests- Accuracy& Reliability

Table B.4.1 depicts the location performance of Motorola for the 33 test sites selected for the trial. Precise surveying equipment was utilized in the determination of ground truth at all these locations, thus reducing the error to 50 cm. The results presented provide accuracy and yield for the whole sample set as well as the set selected by Motorola (Selected Samples). As mentioned in Section 3.1, the selected samples are based on the data exclusions that Motorola deemed necessary in light of the system malfunctions during the trial.

The results show the need for further development of the system and refinement of the location algorithm. At no site did the results meet the FCC mandate. The exclusion of the data samples by Motorola did improve the accuracy at most points, however the accuracy still did not satisfy the mandate requirements. Furthermore the yield was very low.

Overall, the FCC mandate was not satisfied in any of the locations. As depicted in Table B.4.2, the results were better in Urban and Suburban areas and worst in the case of indoor tests performed. Overall the yield for all the 3819 calls made was 48% whereas the yield for the selected samples of 1231 was 72.6%. Figures B.4.1 and B.4.2 depict the scattering of the location error for the two groups of data analyzed. Note that a significant East-West error reduction is evident in the selected data.

Table B.4.1 Motorola Stationary Accuracy and Reliability

		All Samples			*Selected Samples*		
	Environment	**67% Error (meters)**	**95% Error (meters)**	**Yield (%)**	**67% Error (meters)**	**95% Error (meters)**	**Yield (%)**
Site01	Suburban	434	H	50.0	454	H	58.3
Site02	Suburban	640	H	65.7	379	H	83.9
Site03	Suburban	370	H	76.5	491	H	90.6
Site04	Suburban	592	H	47.7	625	H	69.2
Site05	Suburban	582	H	57.4	402	897	81.6
Site06	Suburban	H	H	50.9			
Site07	Indoor	H	H	1.5	H	H	0.0
Site08	Water	917	H	38.7			
Site09	Water	757	H	61.9			
Site10	Indoor	H	H	5.1	H	H	33.3
Site11	Indoor	354	H	40.8	262	610	86.7
Site12	Urban	388	H	72.6	164	524	97.1
Site13	Indoor	341	342	1.8			
Site14	Urban	455	918	74.4	380	962	100.0
Site15	Urban	358	H	69.4	301	568	88.9
Site16	Urban	384	865	52.7	202	H	100.0
Site17	Urban	833	911	14.3	833	910	55.0
Site18	Urban	616	955	28.9	648	878	28.6
Site19	Urban	482	H	62.2	316	H	72.2
Site20	Urban	820	H	64.2	652	H	77.6
Site21	Urban	324	979	77.1	330	844	90.8
Site22	Indoor	457	H	23.3	425	H	100.0
Site23	Urban	304	H	56.7	310	H	66.2
Site24	Urban	247	972	59.6	237	H	75.0
Site25	Urban	630	H	51.7	408	H	62.5
Site26	Urban	481	991	75.0	481	991	75.0
Site27	Rural	H	H	47.0	H	H	68.9
Site28	Rural	624	H	25.6			
Site29	Rural	821	H	48.0	750	H	64.9
Site30	Rural	414	895	45.1	344	894	60.0
Site31	Rural	H	H	43.9	H	H	66.3
Site32	Indoor	513	H	75.3	332	661	100.0
Site33	Indoor	320	H	90.8	281	H	95.5

H signifies a High value beyond the limits of the analysis program

It is of interest to note the Water sites selected were not in any of the zones depicted in Figure B.2-1.

Table B.4.2 Motorola Accuracy and Reliability by Environment

	All Samples (3819 Calls)			*Selected Samples (1231 Calls)*		
Environment	67% Error (meters)	95% Error (meters)	Yield (%)	67% Error (meters)	95% Error (meters)	Yield (%)
Urban	438	H	58.8	345	H	74.2
Suburban	542	H	57.6	455	H	77.1
Rural	834	H	42.3	858	H	64.7
Water	936	H	48.4			
Indoor	401	H	27.8	270	H	76.6
All Locations	***545***	***H***	***48.0***	***462***	***H***	***72.6***

Figure B.4.1 Error Scatter of all Stationary points

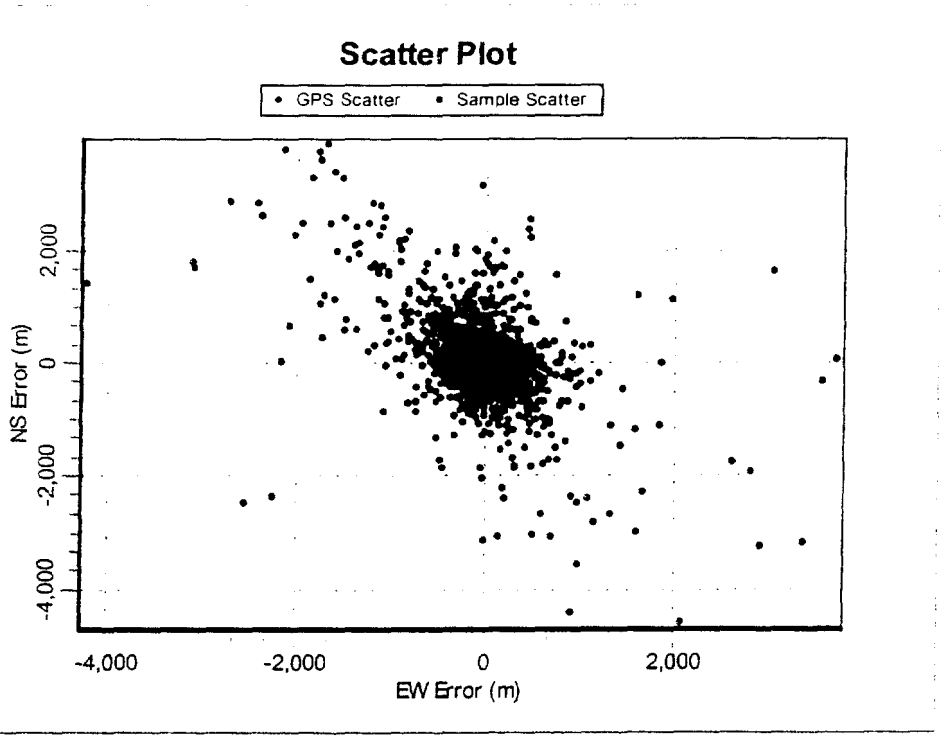
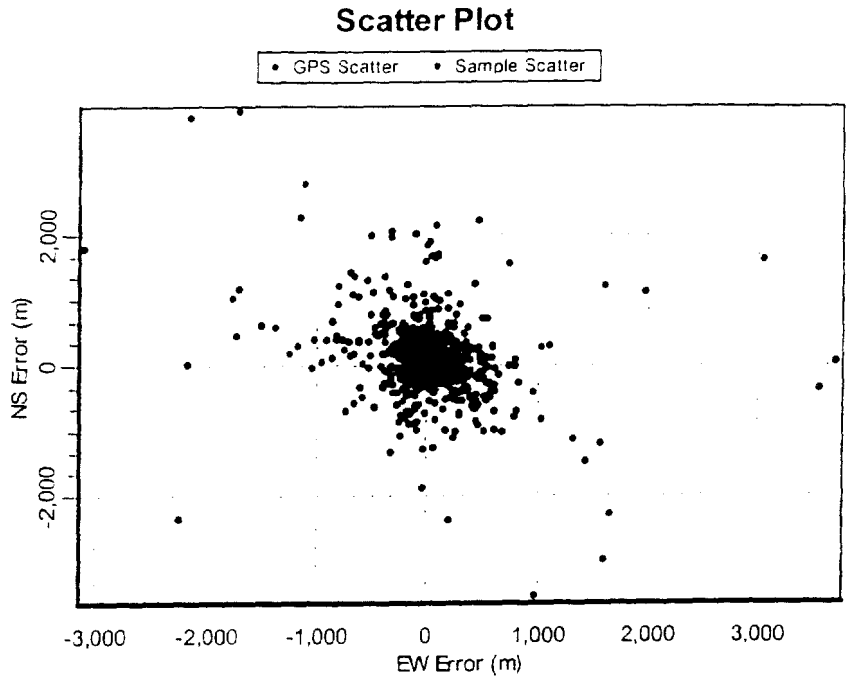


Figure B.4.2 Error Scatter of Selected Stationary points



B.4.2 Moving Tests- Accuracy & Reliability

Motorola did not participate in any of the moving tests.

B.4.3 In/Out Tests- Accuracy & Reliability

The In/Out tests were conducted at six locations within the test area. These tests were devised to show the impact of the body of the vehicle on accuracy and yield of the location system. The results are presented in Table B.4.3 show a similar performance as that of stationary tests.

Table B.4.3 In/Out Test Results

	Inside Vehicle		Outside Vehicle	
Location	**67% Error (meters)**	**95% Error (meters)**	**67% Error (meters)**	**95% Error (meters)**
L-1	922	H	H	H
L-2	H	H	H	H
L-6	H	H	H	H
L-18	407	408	407	408
L-24	745	746	745	948
L-25	540	H	540	H

B.4.4 Processing Time

Due to the non-real time nature of the test system, the processing time is not applicable.

B.5. Conclusion

Motorola provided a technology that is in a fairly early stage of research and development. The demonstrated performance did not meet the FCC requirements. Based on the observed performance, extensive research and development is needed before an operational system can be demonstrated.

C.1. Overview

US Wireless (USW) employed a hybrid solution that combined Multipath Characterization with AOA capability. The system was comprised of two basic components: a collection of RadioCamera™ Base Units (RBUs) and a Regional Network Operating Center (RNOC). The RBUs measured the wireless signals, created the location signatures, and determined the caller's location. The RNOC, consisting of a number of processors networked to RBUs, completely controlled all the RBUs, directing their activity, receiving and storing location information, and monitoring their performance and operation. Furthermore, the RNOC utilized the DF information as an added filter to exclude the outliers. Furthermore, the RNOC provided the location information to the end user – in this case, USW's data gathering PC located at the central site.

The results presented here are based on the trial conducted from June 2nd to June 7th, 2000 in the Washington, D.C. trial area as defined in the Nextel's Location System Field Evaluation Test Plan dated March 13th, 2000.

Prior to commencement of operation, USW performed the calibration of all sites and gathered the data necessary to perform the position determination in the USW defined test area. The calibration efforts continued on a daily basis during the trial and new calibration was uploaded to the sites on a nightly basis. This was not and is generally not the standard procedure for using the USW system. It proved to be necessary, however, because the initial results obtained showed poor performance and revealed a host of operational problems. Those are explained in detail in the sections to follow in this appendix.

Accordingly the trial results can be viewed as having gone through three phases. The first provided the initial results for the "first" and "best" fixes with both first day and most recent day calibrations. The second phase was for post processed data after some of the operational problems were identified and removed. Finally, the third phase focused on results from the Virginia side of the test area exclusively, after more careful system calibrations had been performed and all known anomalies were removed. The data presented in this appendix reflect the initial performance of the system as well as the performance based on the post-trial improvements made by USW.

The combined 67% positioning error for all locations was 567 m in Phase I of the analysis, which improved slightly to 522 m in Phase II. This is obviously well outside the FCC requirement. The 95% error was too high to report meaningfully. These results are in contrast to the much-improved performance in the suburban Virginia segment, which was focused on for Phase III. For stationary tests the 67% positioning error improved to 120 m and the 95% error to 442 m. For the mobile tests, the FCC requirement was met for the suburban surface street but not the freeway, where a large variability was witnessed. Although these results do not yet meet the FCC requirements, they appear to be within achievable distance of that target, assuming USW optimizes its technology for the iDEN network. The detailed results are provided below.

C.2. Configuration of the Test System

The overall configuration of the USW system used in the trial is depicted in Figure C.2.1. USW utilized ten sites spread around the trial area. The coverage of these sites differed from that of the trial area as defined in the test plan. Due to time constraints and the delays in getting Frame Relay (FR) connections, USW utilized microwave links to make the necessary connections from its sites to the RNOC processor located at the Key Bridge site.

At each site an RBU and a six-element antenna array were deployed to perform the location processing and direction finding functions. Figure C.2.2 shows the antenna installation at the Key Bridge site.

Prior to the commencement of the trial, US Wireless test teams utilized four frequencies emitted from a mobile test bed to form the pattern tables at each RBU. During this calibration period, all RBUs in an area recorded the relevant information from all the four frequencies forming tables that are used in the actual position determination process. The calibration efforts continued on a daily basis during the trial and new calibration was uploaded to the sites on a nightly basis.

No connections from the RBUs to Nextel's base stations were made. The only connection

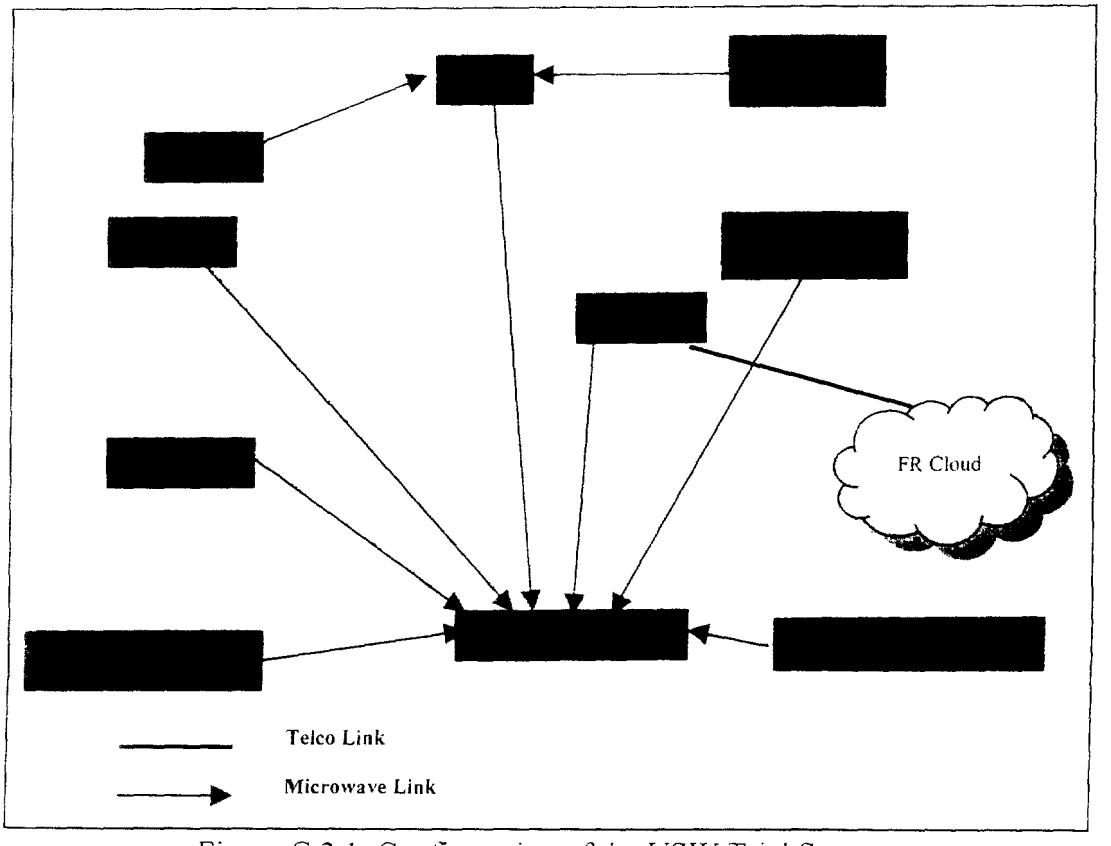


Figure C.2.1. Configuration of the USW Trial System

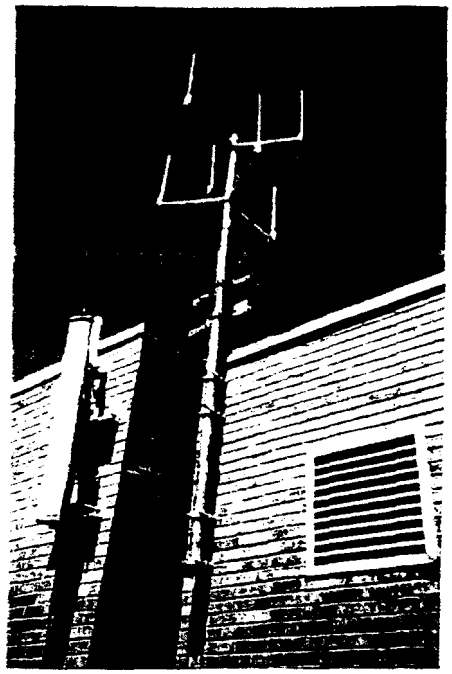


Figure C.2.2. DF Array

to Nextel was through a telco connection to BSC-25 that provided the call initiation, termination, and handover messages to the RNOC.

C.2.1 Area Boundaries and USW Deployment

The area identified by USW was smaller than the trial area. This reduction was due to USW's inability to find enough sites to cover the trial are. Figure C.2.3 depicts the USW area. In Figure C.2.4 the USW boundary is compared to that of the trial area showing the fact that some test points ended up outside the USW area. As evident by the data in section C.4, this variation did not impact the results.

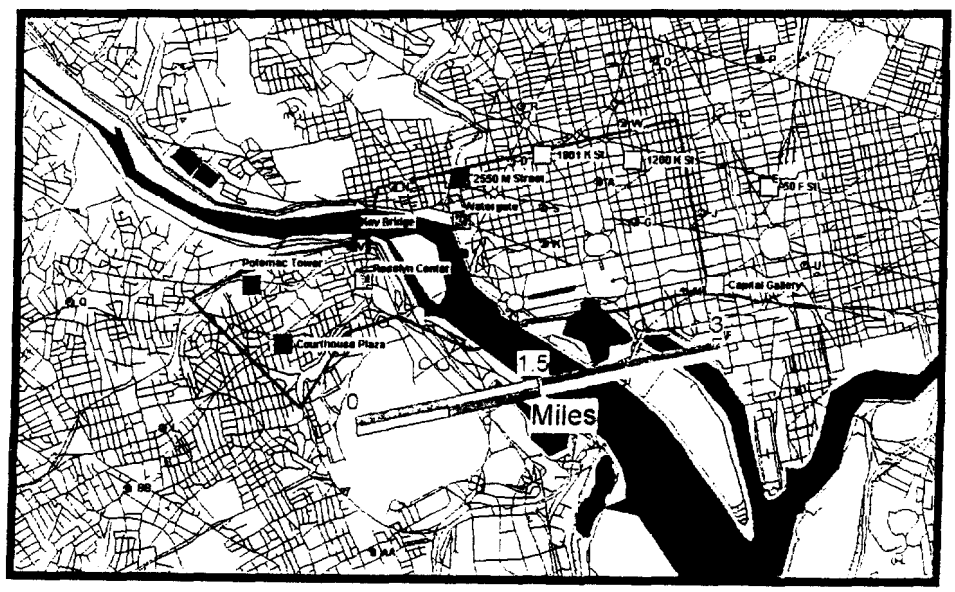


Figure C.2.3. USW Deployment in the Trial Area

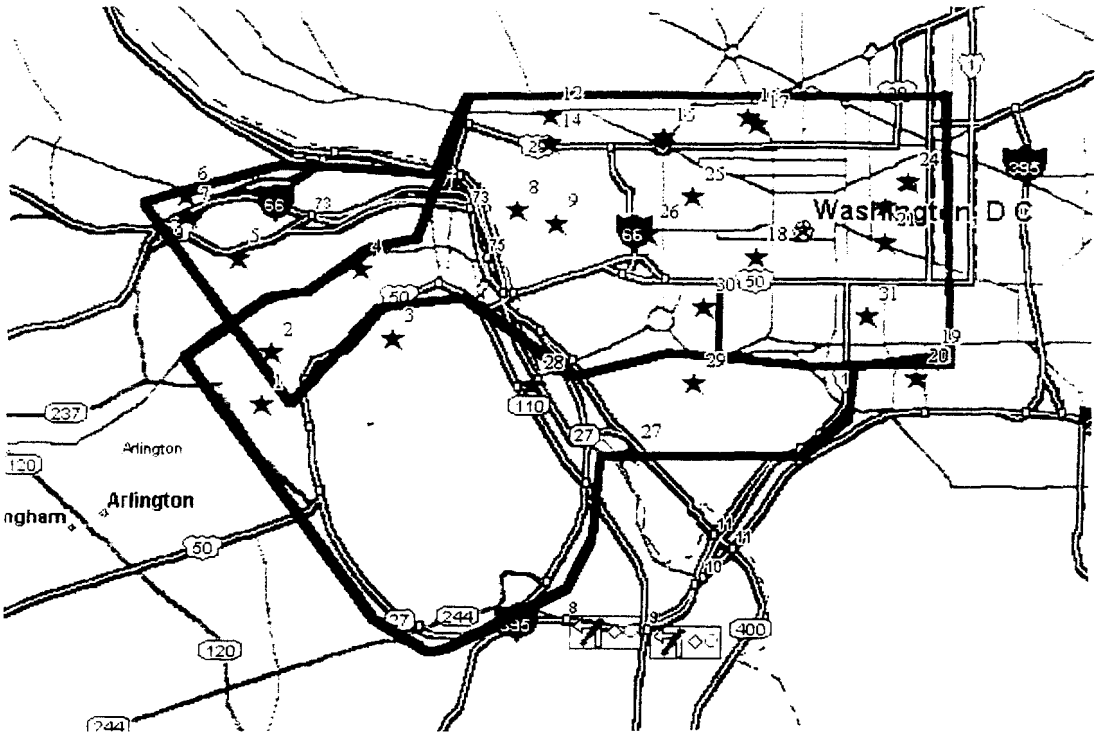


Figure C.2.4. Trial Area (Black Contour) versus USW Coverage (Green)

C.3. Mode of Operation

Except for the duration of the call, which was increased to 30 seconds, the mode of operation was identical to the mode defined in the test plan. At every location the test engineers placed 10 calls per visit. The system received a trigger from Nextel's BSC-25 that signified the start of the call which resulted in the initiation of operation by the USW processing software. Furthermore, the same interface was utilized for receiving call termination and handoff messages from the BSC. The USW system determined the position of the caller several times during the call. The positions were displayed on a map as they become available.

To ensure that detailed information was made available to Nextel, USW supplied data files that contained the first location, the best location, and all locations calculated during the call. USW utilized their location quality algorithm to select the best location out of several samples gathered during the 30 second call. The basis of the trial was the determination of system quality based on the "First Fix"; nevertheless, due to low quality of the initial results, the main body of the analysis was performed on the "Best Fix" results.

C.3.1 Deviation from Test Plan

- Two Urban locations, Sites 17 and 26, were eliminated due to the fact that all calls were assigned to a different BSC than BSC-25.

- The operational stability of the system was compromised by uploading calibration tables on a nightly basis. USW had to provide post-processed data that utilized the first day's calibration table as well as the most recent day's calibration. The latter table was used to provide reference points for this analysis (rather than the baseline plan of using the calibration table fixed on the first day of the trial).

- The initial analysis led to highly inaccurate results thus leading to the discovery of several issues, which were worked on by USW. Due to these inaccuracies, the analysis was mainly performed on the "Best Fix" as defined by USW. The analysis was performed in three phases as follows:

  - Phase I. Trial results were provided after the trials. The results included the "First Fix" and "Best Fix" results utilizing the 1st day's calibration (CAL) table and the last day's CAL table. The results were highly inaccurate regardless of the CAL table or the fix that was used. TechnoCom made the decision to utilize the last day's CAL data due to slightly better response.

  - Phase II. Upon a detailed study of the raw data by USW, issues related to the latency in the microwave links, lack of adequate calibration data, poorly optimized collection parameters, and inaccuracy of quality factor estimates were identified. USW resolved the microwave latency issues and provided post processing data to reflect the changes. The analysis of data showed some improvement in the Virginia side of the trial region.

  - Phase III. USW concentrated on the Virginia side and test drove the area. They eliminated all the known anomalies, including discarding all low performing calibration files, incorporation of optimized RadioCamera parameters, and restricting usage to those sites covering Virginia. Improvements in the results were significant. Due to the less than optimal CAL data on the DC side, USW could not provide any data in an Urban environment.

C.4. Trial Results

C.4.1 Stationary Tests- Accuracy& Reliability

Table C.4.1 depicts the location performance of USW for the 33 test sites selected for the trial. Note that USW provided a fix for every call placed, therefore the yield was 100% throughout the trial. The results tabulated are based on the analysis of the Best Fix locations provided by USW for the three phases of the analysis defined in the previous section. The First Fix analysis showed very poor performance in Phase I and Phase II, hence only the results of First Fix analysis for Phase III are presented in Table C.4.2. As depicted in Table C.4.2 there is no consistent relationship between accuracy and the type of fix, indicating the lack of a reliable methodology in measuring the quality of the fix.

The limited size of the samples unfortunately preclude drawing conclusions on the efficacy of USW's quality factor.

As depicted in Figure C.4.1 there was a significant improvement due to the modifications made in Phase III, however the results show great variability from one location to another. The FCC accuracy requirements for network-based solutions was not met at any point until the improvements of Phase III were made. Even then, the mandate was only met at three out of the eight sites analyzed. The results for the various environments are summarized in Table C.4.3. Clearly, the performance in the Suburban and Rural areas is much better than in the Urban areas. According to USW, this bias is due to the poor calibration performed in the DC area, which is where all the urban sites are. Because of this reasoning, the suburban and rural sites, all located in Virginia, were post processed to lead to the results presented under Phase III.

Figures C.4.2 to C4.4 show the scattering of the location error for Virginia and DC in Phase II and Phase III of the analysis. Clearly, Phase III improvements dramatically reduced the spread of errors in Virginia.

Table C.4.1 USW Stationary Accuracy and Reliability (Best Fix)

		Phase I		*Phase II*		*Phase III*	
	Environment	**67% Error (meters)**	**95% Error (meters)**	**67% Error (meters)**	**95% Error (meters)**	**67% Error (meters)**	**95% Error (meters)**
Site01	Suburban	103	572	110	H	91	303
Site02	Suburban	871	H	H	H	151	239
Site03	Suburban	712	H	118	H	97	135
Site04	Suburban	149	316	148	736	100	554
Site05	Suburban	147	519	132	177	90	122
Site06	Suburban	483	H	425	H	441	540
Site07	Indoor	262	H	199	H	145	228
Site08	Water	H	H	H	H		
Site09	Water	H	H	H	H		
Site10	Indoor	H	H	H	H		
Site11	Indoor	H	H	H	H		
Site12	Urban	297	H	383	H		
Site13	Indoor	H	H	H	H		
Site14	Urban	H	H	H	H		
Site15	Urban	323	H	226	H		
Site16	Urban	362	H	572	H		
Site17	Urban			264	H		
Site18	Urban	126	920	127	242		
Site19	Urban	H	H	H	H		
Site20	Urban	H	H	H	H		
Site21	Urban	182	H	236	H		
Site22	Indoor	201	765	198	H		
Site23	Urban	134	457	218	H		
Site24	Urban	277	H	247	H		
Site25	Urban	280	555	259	531		
Site26	Urban			278	472		
Site27	Rural	958	H	946	H		
Site28	Rural	168	H	119	315	57	313
Site29	Rural	87	143	94	841		
Site30	Rural	870	H	750	H		
Site31	Rural	177	H	184	H		
Site32	Indoor	128	211	128	H		
Site33	Indoor	128	336	131	H		

H signifies a High value beyond the limits of the analysis program

Table C.4.2 Phase III Performance—First versus Best Fix

		First Fix		*Best Fix*	
	Environment	**67% Error (meters)**	**95% Error (meters)**	**67% Error (meters)**	**95% Error (meters)**
Site01	Suburban	90	304	91	303
Site02	Suburban	120	415	151	239
Site03	Suburban	99	207	97	135
Site04	Suburban	109	H	100	554
Site05	Suburban	94	170	90	122
Site06	Suburban	428	773	441	540
Site07	Indoor	145	204	145	228
Site28	Rural	60	313	57	313

Figure C.4.1 Improvements in Virginia

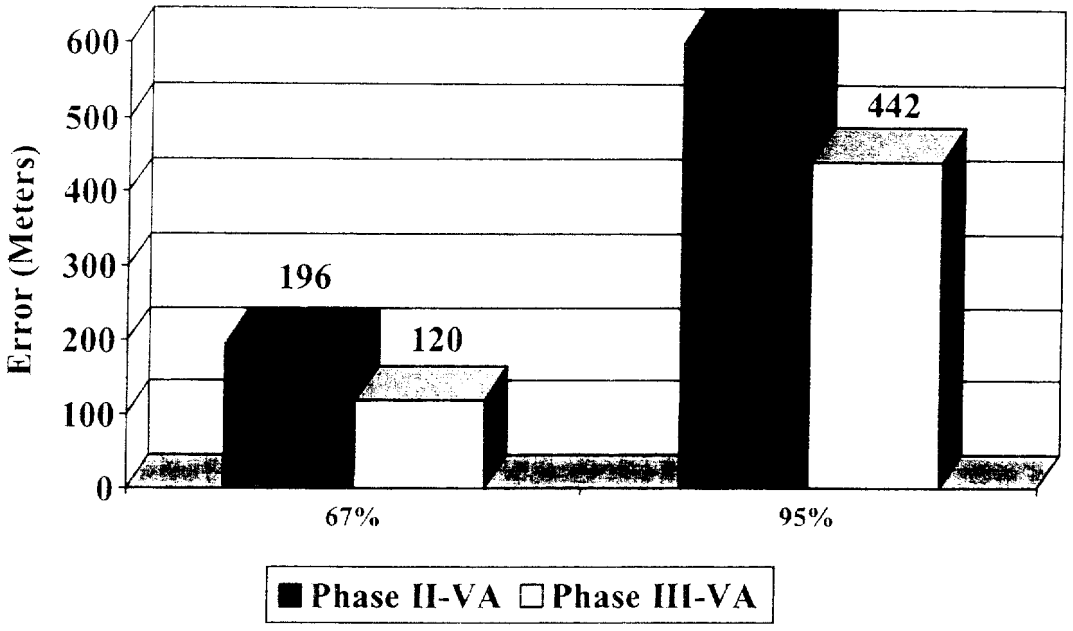


Table C.4.3 USW Accuracy and Reliability by Environment

	Phase I		*Phase II*		*Phase III*	
Environment	67% Error (meters)	95% Error (meters)	67% Error (meters)	95% Error (meters)	67% Error (meters)	95% Error (meters)
Urban	356	H	361	H		
Suburban	325	H	232	H	162	316
Rural	257	H	183	H	57	313
Water	H	H	H	H		
Indoor	H	H	H	H	145	228
All Locations	***567***	***H***	***522***	***H***	***120***	***442***

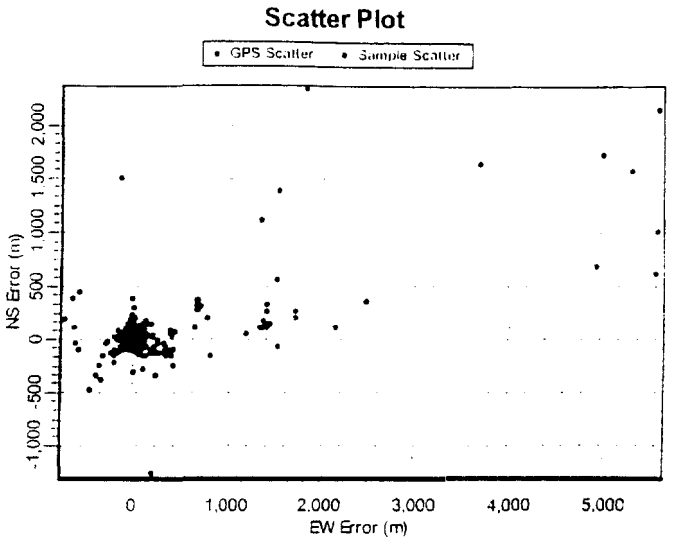


Figure C.4.2
VA Phase II

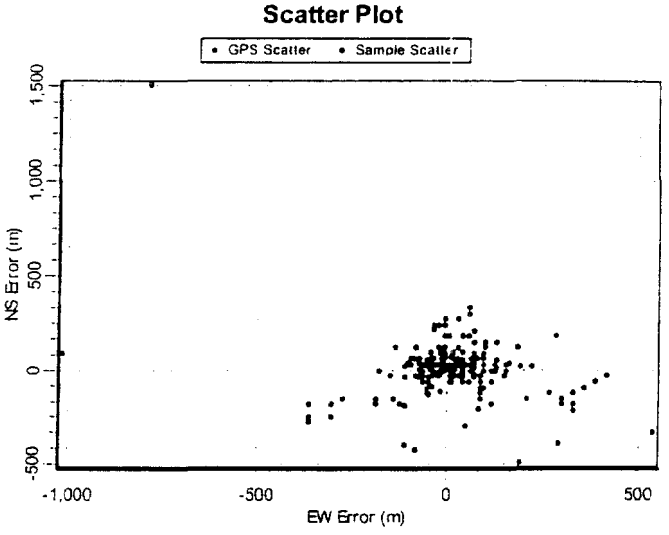


Figure C.4.3
VA Phase III

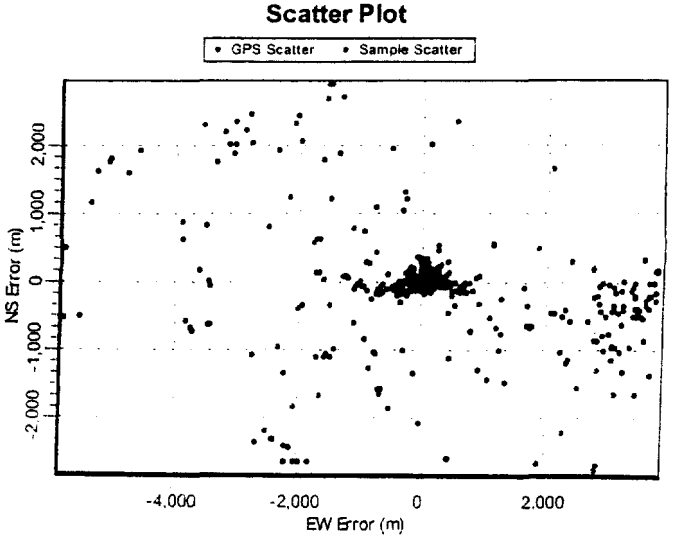


Figure C.4.4
DC. Phase II

C.4.2 Moving Tests- Accuracy based on Phase III

The moving tests were performed on three or four occasions for each test route. Two freeway routes and the suburban route were in Virginia; however, all calls on one of the freeway routes would end up on the wrong BSC, thus limiting the analysis to one freeway and one suburban route. As shown in Figures C.4.5 and C.4.6, the FCC mandate is met on the Suburban route, however there is large variability in the results obtained on the freeway. The freeway track for Visit 2 (the best visit) is shown in Figure C.4.6.

Figure C.4.5 Phase III moving Tests – 67% Error Statistics

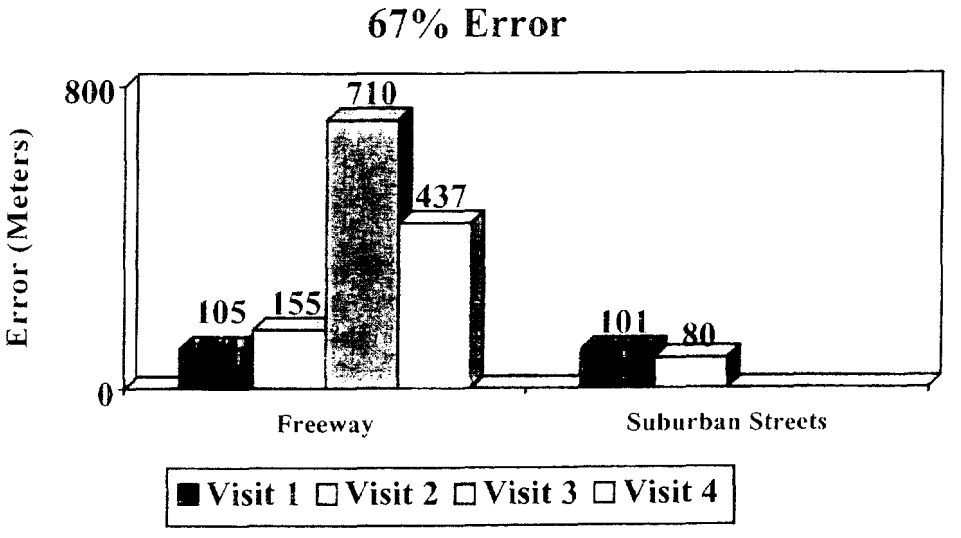


Figure C.4.6 Phase III moving Tests – 95% Error Statistics

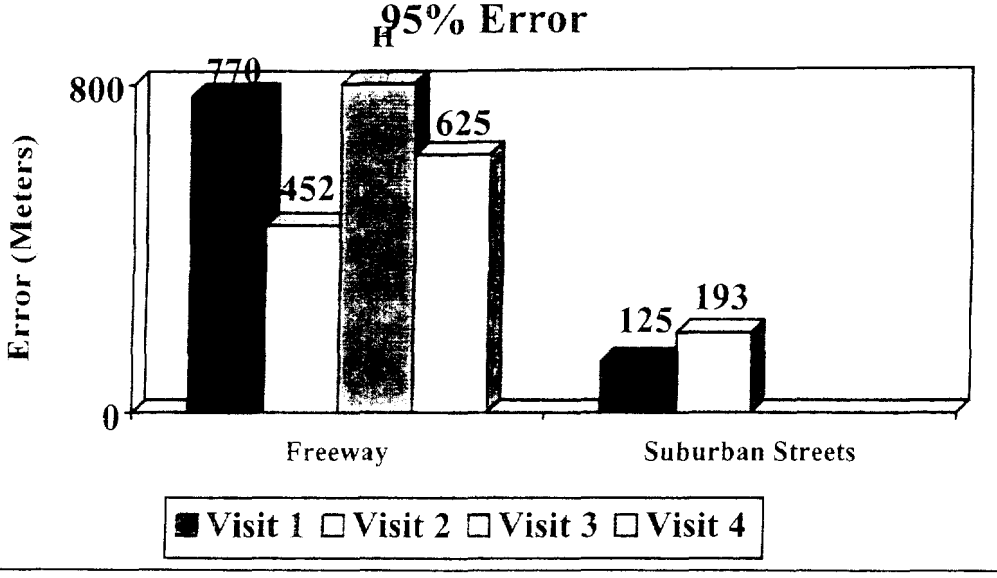
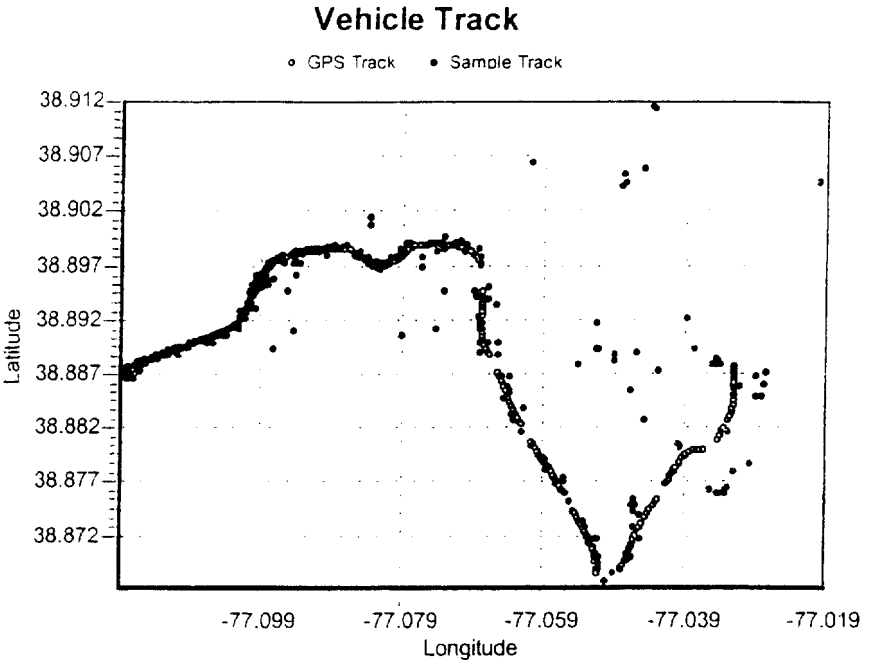


Figure C.4.6 Moving Track- Freeway Visit 2



C.4.3 In/Out Tests- Accuracy& Reliability

The In/Out tests were conducted at five locations within the trial area. Only Locations 2 and 6 were post processed in Phase III. These tests were devised to show the impact of the body of the vehicle on accuracy and yield of the location system. As with all the other tests performed, the yield stayed at 100%. Table C.4.4 shows that the error is reduced when the phone is placed outside the vehicle at Location 2, however a slight degradation in performance is seen at Location 6. The very limited size of the sample precludes drawing any conclusion in this area.

Table C.4.4 In/Out Test Results

	Inside Vehicle		Outside Vehicle	
Location	**67% Error (meters)**	**95% Error (meters)**	**67% Error (meters)**	**95% Error (meters)**
L-2	243	401	116	202
L-6	151	434	151	508

C.4.4 Processing Time

Due to the lack of adequate samples and the utilization of the best fix, the processing delay was not analyzed.

C.5. Conclusion

USW system developed for iDEN was tested in various environments. The performance in areas where intensive calibration and testing was performed shows good potential for the development of a system that can operate in all the operational environments. Overall, the demonstrated performance did not meet the FCC requirements. Based on the observed performance, extensive testing and optimization on an iDEN network is required before USW's RadioCamera™ system can be considered as a viable solution.